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THE ENERGY OF EVOLUTION.

BY E. D. COPE.

1 PRELIMINARY.

In considering the dynamics of organic evolution, it will be convenient to commence by considering the claims of Natural Selection to include the energy which underlies the process. That Natural Selection cannot be the cause of the origin of new characters, or variation, was asserted by Darwin;[1] and this opinion is supported by the following weighty considerations.

(1) A selection cannot be the cause of those alternatives from which it selects. The alternatives must be presented before the selection can commence.

(2) Since the number of variations possible to organisms is very great, the probability of the admirably adaptive structures which characterize the latter having arisen by chance is extremely small.

(3) In order that a variation of structure shall survive, it is necessary that it shall appear simultaneously in two individuals of opposite sex. But if the chance of its appearing in one individual is very small, the chance of its appearing in two individuals is very much smaller. But even this concurrence of chances would not be sufficient to secure its survival, since it would be immediately bred out by the immensely prepon-

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[1] Origin of Species, Ed. 1872, p. 65.

derant number of individuals which should not possess the variation.

(4) Finally, the characters which define the organic types, so far as they are disclosed by paleontology, have commenced as minute buds or rudiments, of no value whatsoever in the struggle for existence. Natural Selection can only effect the survival of characters when they have attained some functional value.

In order to secure the survival of a new character, that is, of a new type of organism, it is necessary that the variation should appear in a large number of individuals coincidentally and successively. It is exceedingly probable that that is what has occurred in past geologic ages. We are thus led to look for a cause which affects equally many individuals at the same time, and continuously. Such causes are found in the changing physical conditions that have succeeded each other in the past history of our planet, and the changes of organic function necessarily produced thereby.

2 BATHMOGENESIS.

If we view the phenomena of organic life from the standpoint of the physicist, the first question that naturally arises in the mind is as to the kind of energy of which it is an exhibition. Ordinary observation shows that organic bodies perform molar movements, and that many of them give out heat. A smaller number exhibit emanations of light and electricity. Very little consideration is sufficient to show that they include among their functions chemical reactions, a conviction which is abundantly sustained by researches into the physiology of both animals and plants. The phenomena of growth are also evidently exhibitions of energy. The term energy is used to express the motion of matter, and the building of an embryo to maturity is evidently accomplished by the movement of matter in certain definite directions. The energy which accomplishes this feat is, however, none of those which characterize inorganic matter, some of which have just been mentioned, but, judging from its phenomena, is of a widely different character. If we further take a broad view of the general process of progressive evolution, which is accomplished by successive modifications of this growth-energy, we see further reason for distinguishing it widely from the inorganic energies.

It is customary to distinguish broadly between inorganic and organic energies, as those which are displayed by non-living and living bodies. This classification is inexact, since, as already remarked, nearly all of the inorganic energies are exhibited by living beings. A division which appears to be, with our present knowledge, much more fundamental, is into the energies which tend away from, and those which tend towards, the phenomena of life. In other words, those which are not necessarily phenomena of life, and those which are necessarily such. And the phenomena of life here referred to are the phenomena of growth and evolution, as distinguished from all others. I have termed[2] these classes the Anagenetic, which are exclusively vital, and the Catagenetic, which are physical and chemical. The Anagenetic class tends to upward progress in the organic sense; that is, toward the increasing control of its environment by the organism, and toward the origin and development of consciousness and mind. The Catagenetic energies tend to the creation of a stable equilibrium of matter, in which molar motion is not produced from within, and sensation is impossible. In popular language the one class of energies tends to life; the other to death.

That the Catagenetic energies whether physical or chemical, tend away from life is clear enough. Thus molar motion unless continuously supplied, or directed by a living source, speedily ceases, being converted by friction into heat, which is dissipated. And were we to suppose a case where friction is non-existent, motion would remain molar, and no phenomena of organic life would result, and sensation could not arise. The same is true of molecular movements under the same conditions. Chemical reactions, which are fundamental in world-building, result in the production of solids and the radiation of heat. The most familiar example, that of oxydation, presents us with the case of a gas becoming a liquid or a solid with the evolution of heat. The endothermic reaction, where matter undergoes a change of molecular aggregation the reverse of that just mentioned, with the absorption of heat, as in the case of several hydrogen compounds, is rare in nature, where free from organic complications, and is generally soon reversed by further reactions. Finally cosmic creation involves the perpetual radiation of heat into space, and the gradual reduction of all forms of matter to the solid state.

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[2] The Monist Chicago, 1893, p. 630.

In the anagenetic energies, on the other hand, we have a process of building machines, which not only resist the action of catagenesis, but which press the catagenetic energies into their service. In the assimilation of inorganic substances they elevate them into higher, that is more complex compounds, and raise the types of energy to their own level. In the development of molar movements they enable their organisms to escape many of the destructive effects of catagenetic energy, by enabling them to change their environment; and this is especially true in so far as sensation or consciousness is present to them. The anagenetic energy transforms the face of nature by its power of assimilating and recompounding inorganic matter, and by its capacity for multiplying its individuals. In spite of the mechanical destructibility of its physical basis (protoplasm), and the ease with which its mechanisms are destroyed, it successfully resists, controls, and remodels the catagenetic energies for its purposes.

The anagenetic power of assimilation of the inorganic substances is chiefly seen in the vegetable kingdom. Atmospheric air, water and inorganic salts furnish it with the materials of its physical basis. Then from its own protoplasm it elaborates by a catagenetic retrograde metamorphosis, the mostly non-nitrogenous substances, as wood (cellulose), waxes, oils and alkaloids, and it may take up inorganic substances and deposit them without alteration in its cells. Many of the compounds elaborated by plants and animals have been manufactured of latter time by chemists. The discovery that the living organism is not necessary for the production of these substances has led to the hasty conclusion that the supposed distinction between "organic" and "inorganic" energy does not exist. But the elaboration of these substances is not accomplished by anagenetic or "vital" energy, but by a process of running down of the higher compound protoplasm, which is catagenesis. No truly anagenetic process has yet been imitated by man.

All forms of functioning of organs, except assimilation, reproduction and growth, are catagenetic. That is, functioning consists in the retrograde metamorphosis of a nitrogenous organic substance or proteid with the setting free of energy. The proteid is decomposed in the functioning tissue into carbon dioxyd, water, urea, etc., and energy appears in the muscle as contraction, in the glands as secretion, and in all parts of the body as heat. The general result of physiologic research is, that the decomposition of the blood is the source of energy, while the tissue of each organ determines the character of that energy. That the tissue itself suffers from wear, and requires repair, is also true, but to a less extent than was once supposed.

In the anagenetic process of the growth of the embryo the case is different. Here the processes of functioning of organs are in complete abeyance, the nutritive substance is not entirely broken down in chemical decomposition, but it is in great part elaborated into tissues and organs. All the mechanisms necessary to the mature life of the individual are constructed by the activity of the special form of energy known as growth-energy or Bathmism. It is the modifications of this energy which constitute evolution, and it is these to which we will hereafter direct our attention. Its simplest exhibition is the subdivision of a unicellular protoplasmic body into two or more individuals or structural units of a multicellular organism. Further division of the latter does not abolish the individual, but extends it, and we now observe the elaboration of different structural types to become a conspicuous function of this form of energy. In other words a once simple energy becomes specialized into specific energies, each of which, once established, pursues its mode of motion in opposition to all other modes not more potent than itself. Besides the evident truth of the proposition than a mode of building is a mode of motion, we have another very good reason for believing in the existence of a class of bathmic or growth-energies. This is found in the phenomena of heredity. The most rational conception of this inheritance of structural characters is the transmission of a mode of motion from the soma to the germ-cells. This is a far more conceivable method than that of the transmission of particles of matter, other than the ordinary material of nutrition. The bathmic theory of heredity bears about the same relation to a theory of transmission of the pangenes of Darwin, or the ids of Weismann, as the undulatory theory of light and other forms of radiant energy does to the molecular theory of Newton. I have therefore assumed as a working hypothesis the existence of the bathmic energy, and will enquire how far the facts in our possession sustain it. In doing so it will be necessary to elaborate the theory so as to render clearer its application to specific cases. The fact to be accounted for is its specialization into so many diverse specific forms.

A further indication of the existence of the bathmic energy is the quantitative limitation to which growth is obedient. Thus the successive stages of embryonic growth are limited in number in each species. The dimensions of many species are limited within a definite range. The duration of life, or of the functioning organic machine, has a definite limit in time. All this means that a certain limited quantity of energy is at the disposal of each individual organism.

In " The Origin of the Fittest," I have endeavored to show what causes have been and are efficient in the production of different types of organic life, through the modifications of the bathmic energy. We will now briefly consider to the question of the origin of the living substance, protoplasm or sarcode, which exhibits bathmism.

If the tendency of the catagenetic energies is away from vital phenomena, it is impossible that they, or any one of them, should be the cause of the origin of living matter. This logical inference is confirmed by the failure of all attempts to demonstrate spontaneous generation of living organisms from inorganic matter. Further, the principle of continuity leads us to infer that the energy which produced organic matter must be identical with or allied to that which is the efficient agent in progressive evolution of organisms, and is, therefore, anagenetic. Such a conclusion may seem to lead to a dualism which is itself opposed to the principle of continuity or uniformity, and which is opposed to experience of the phenomena of energy in general. How is uniformity to be harmonized with the hypothesis of two types of energy acting in different directions, apparently in opposition to each other? Since facts and logic do not support the derivation of the anagenetic from the inorganic energies, can the reverse process, the derivation of the catagenetic from the anagenetic be and have been the order of nature? In support of this hypothesis, we have the universal prevalence of the retrograde metamorphosis of energy in both the inorganic and organic kingdoms. Phenomena of structural degeneracy are well known in the organic world, and purely chemical phenomena in both organic and inorganic processes are all degenerate. It appears then much more probable that catagenesis succeeds anagenesis as a consequence, and does not precede it as a cause. In other words, it is more probable that death is a consequence of life, rather than that the living is a product of the non-living. I have therefore given to that energy which is displayed by the plant in the elaboration of living from now living matter the name of antichemism.[3] Thus while the heat of the sun is necessary to the building of protoplasm, within a certain range of temperature, this form of energy has its opportunity.

In order to present more clearly the views enunciated in the preceding pages, I give a synoptic table of energies.

I Anagenetic	Organic	Antichemism. Bathmism.
II Catagenetic	Exclusively organic	Neurism. Myism.
	Inorganic	Radiant Energy. Chemism. Cohesion. Gravitation.

3 THE FORMS OF BATHMISM.

The innumerable structures which are due to the activity of Bathmisms may be supposed to result from the composition of this energy with others which are present in the organism or in the environment, or both. Ryder has called the exhibition of growth energy Ergogenesis,[4] and he calls attention to the fact that it appears under two aspects. In the first, Ergogenesis is due to mechanical causes resident in the organism exclusively, and it expresses the sum of the bathmic energy inherited from the parents of the growing organism. To this conservative expression of Bathmism he gives the name of Statogenesis. In the second aspect of Ergogenesis, the course of growth (ontogeny) is determined by motion from sources external to the germ cell. It is this which modifies ontogeny and produces those changes of structure which constitute Evolution. To this aspect of growth I have given the name Kinetogenesis.[5] As Statogenesis expresses simple growth force, and Kinetogenesis the additional growth, which is evolution, the latter is chiefly considered here.

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[3] American Naturalist, 1884, p. 979. Origin of the Fittest, 1887, p. 431.

Kinetogenesis is of two kinds; viz., the changes in growth which are due to the interference of molecular energies only, and those which are due to molar movements. The former type of evolutionary growth I propose to call Physiogenesis; and I propose to restrict the term kinetogenesis to the latter class. To the total evolutionary energy or energies due to external interference, the Kinetogenesis of Ryder, I propose to apply the term Bathmogenesis. The relation of these modes, and their corresponding names may be expressed as follows:

$$\text{Ergogenesis}\begin{cases}\text{Statogenesis}\\ \text{Bathmogenesis.}\begin{cases}\text{Physiogensis.}\\ \text{Kinetogenesis.}\end{cases}\end{cases}$$

Statogenesis, I shall hereafter endeavor to show, is an automatic product of Bathmogenesis.

The first step in the order of Bathmogenetic action is the effect of stimuli on an animal which is no longer protected by the parent or by parental products (egg-shell) as an embryo. Changes may be effected in the weight, color, and in functional capacity by temperature, humidity, food, etc., thus exhibiting physiogenesis. Or changes in the size and form of parts of the body may be produced by movements of the organism, or of its environment, so displaying Kinetogenesis. So long as these modifications of structure should be confined to the individuals thus modified, there would be no evolution. A second generation, if not subjected to the same stimuli, would not possess the modifications; and their possession of them would depend entirely on the amount of stimulus. In other words there would be no accumulation of modification. It has, however, been generally believed that these modifications are inherited, and I think it can be shown that this belief rests on a solid basis. Meanwhile I call the Bathmogenesis which does not extend beyond the generation in which it appears, autobathmogeny.

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[4] Proceeds. Amer. Philos. Soc. 1893, p. 194.

[5] Origin of the Fittest, 1887, p. 423. Statogenesis and Kinetogenesis are the equivalents of my Growth Force and Grade Growth Force, Proceeds. Amer. Philos. Soc. 1871, p. 253.

The quantitative relation which necessarily exists between Bathmism and its sources may be expressed as follows, with due recognition of the fact that such expression does not rest upon any experimental tests. Statogenesis is work done in the construction of tissues like those of the parent and without interference. Here we have the molecular energy of the parent (either as protozoon or oösperm) temporarily converted in part into the molar movements observed to be concomitants of segmentation; to be represented in the completed tissue by the mutual tensions by virtue of which each structural element maintains its integrity. It is evidently a process of metamorphosis of energy in which there is less waste than in any other known to us. Embryonic growth is accompanied by a very slight dissipation of heat, though a slight rise of temperature is noticeable in the eggs of cold-blooded animals and in flowers, when reproduction is active. The products of breaking down are equally rare in embryonic growth, and both this and the dissipation of heat are evidently largely due to the changes wrought in non-cleavable nutritive substances with which the yolks are sometimes charged. It is probably to accomplish this process that the oxygen necessary for the embryonic growth is used. How much loss is due to cell division itself is not known, but it must be very little if any. We have here a nearly perfect conversion of energy. Theoretically we have anagenesis wherever the up-building exceeds the down-breaking.

The attempt to realize in the imagination the modus operandi of bathmic energy in embryo building takes the following form. It is to be supposed that movement which has been most frequently repeated, and for the longest period, is prepotent, and takes precedence of all others. This is clearly simple cell division, which follows the nutrition supplied by the spermatozoön, and which represents the first act of animal life. Hence, segmentation of the oösperm is the first movement of bathmism. Each subsequent movement appears in the order of potency, which is, other things being equal, a time order, or the order of record. The cause of the localization of tissues and structures is much more difficult to understand than the cause of the order of their appearance. The more energetic part of the process naturally requires the greater space for its products. The ectoderm, which becomes the seat of the nervous axis and its muscular adjuncts, occupies the superficial portions of the yolk. Hence, we may regard this expression of the structural record of these functions as more energetic than that of the record structure of the nutritive functions, which displays itself below the ectoderm. In meroblastic and amphiblastic embryos, the segmentation which develops the nutritive tissues is evidently more sluggish, for the cells are larger and fewer in number than those of the ectoderm.

Can this difference in the segmentations which produce the ectoderm and the endoderm be due to a certain polarity; the male or energetic tendency predominating in the former, and the female in the latter?

External stimuli modify the course of statogeny above described, and by producing new structural records cause a new form of energy, due to composition of the new with the old, and the process of growth then becomes bathmogeny. The external stimuli are molecular or molar, determining physiobathmism or kinetobathmism.

The effect of motion or use on the soma may be conveniently termed autokinetogenesis. Moderate use of a muscle is known to increase its size. Irritation of the periosteum is known to cause deposit of bone. Friction and pressure of the epithelium increases its quantity or changes its form. Increased activity of the functions of nervous tissues increases their relative proportions, as in the enlargement of nerves which replace others which are interrupted by mutilations, etc. On the other hand, it is equally well known that disuse produces diminution of muscular tissue, and through it, a reduction in the quantity of the harder tissue (bone, chitin, etc.) to which it is attached, (as muscular insertions, etc.). It was the observation of such well-known phenomena as these that led Lamarck to advance his doctrine of evolution under use and disuse, and which has led many others to give their adherence to such a view.

Thus much for cell-growth. Another class of modifications of a similar kind may be found in the parts of an organism which consist of a complex of cells, or tissues. Thus the lumen of a small artery is enlarged under the influence of pressure when it is compelled to assume the function of a larger vessel through the interruption of the latter. A part of an internal or external skeleton which is fractured will form an artificial joint at the point of fracture, if the adjacent surfaces are kept in motion. Marey (Animal Mechanism pp. 88–89) says "After dislocations the old articular cavities will be filled up and disappear, while at the new point where the head of the bone is actually placed, a fresh articulation is formed, to which nothing will be wanting in the course of a few months, neither articular cartilages, synovial fluid, nor the ligaments to retain the bone in place." I have given some illustrations of this fact,[6] which have come under my observation, and which have an important bearing on the origin of the articulations of the vertebrate skeleton as I have traced them throughout geological time. I have as I think conclusively shown that these varied structures have been produced by impacts and strains, which are concomitants of the movements of the animals, acting through long periods of time.[7] I have also proposed the

[6] Proceeds. Amer. Philos. Soc. 1892, p. 285.

[7] Mechanical Origin of the Hard parts of the Mammalia, Amer. Journal of Morphology, 1889. Origin of the Fittest, 1887, pp. 305-373.

hypothesis, that such Kinetogenetic organic energies as are not under the control of the organism, are the product of the catagenesis of energies which were at one time under such control.

4 MNEMOGENESIS.

The above term is employed by Prof. Hyatt[8] to characterize the manner in which kinetogenesis is supposed to produce results in inheritance. I have suggested that the phenomena of recapitulation, characteristic of ontogeny (Amer. Naturalist, Dec., 1889), are due to the presence of a record in the germ cells, having a molecular basis similar to that of memory. This view is adopted by Professor Hyatt. I have already referred to it in the preceding pages. The stimuli which are thus recorded are those which produce growth effects in the body or soma, so that each stimulus may have a double influence. For this reason I have termed this theory of the distribution of energy, Diplogenesis (loc. cit.).

The first statement of the mnemonic theory of heredity which I can discover, is that made by Hering in 1870.[9] It is concentrated in the following paragraph: "The appearance of properties of the parental organism in the full-grown filial organism can be nothing else but the reproduction of such processes of organized matter as the germ when still in the germinal vesicles had taken part in; the filial organism remembers, so to speak, those processes, as soon as an occasion of the same or similar irritations is offered a reaction takes place as formerly in the parental organism, of which it was then a part and whose destinies influenced it." In explanation of this theory Hering says: "We notice, further on, that the process of development of the germs which are destined to attain an independent existence, exercises a powerful reaction upon both the conscious and unconscious life of the whole organism. And this is a hint that the organ of germination is in closer and more momentous relation to the other parts, especially to the nervous system, than another organ. In an inverse ratio the conscious and unconscious destinies of the whole organism, it is most probable, find a stronger echo in the germinal vesicles than elsewhere."

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[8] Proceeds. Boston Soc. Nat. Hist. 1893, p. 73.

[9] Address befoie the Imperial Academy of Sciences of Vienna, May 30, 1870, by Edwald Hering.

It is evident that evolutionists are reaching greater harmony of opinions on the question of inheritance, for both sides are adopting the doctrine of Diplogenesis. In fact, the discussion is beginning to be a logomachy dependent on the significance which one attaches to the term, "acquired characters." Thus, Vom Rath, who says he does not believe in the inheritance[10] of acquired characters, remarks: "there is nothing in the way of the opinion that by the continual working of such external influences and stimuli, the molecular structure of the germ-plasma also experiences a change which can lead to a transmission of transformations. Above all, it ought not to be forgotten in this case that the somatic cells are in no way the first to be modified by the stimulus, and that then by some sort of unexplained process (pangenesis or intercellular pangenesis) this stimulus is transmitted generally by these cells to the plasma of the germ cells. The influence on the germ-plasma is rather a direct one, and if by continued influence a transformation of the structure of this plasma takes place and transmission occurs, we have then simply a transmission of blastogenic and by no means of somatogenic characters, and therein is not the slightest admission of the transmission of acquired characters."

This surprising paragraph contains an admission of the doctrine of Diplogenesis, and does not regard the phenomena as including a transmission of acquired characters. Nevertheless, the stimuli traverse the soma in order to reach the germ plasma. Such an energy is evidently then not of blastogenic origin, although it is such in its effects. Moreover, Vom Rath omits to mention the fact that in traversing the soma, the stimulus frequently, if not always, produces effects on the latter similar to those which it produces on the germ plasma. I should call this process the inheritance of an acquired character, even in the case where no corresponding modification appears in the soma, since the causative energy is acquired by the soma, and is not derived from the existing germ plasma.

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[10] Berichte der Naturforsch. Gessel. zu Freiburg Baden. Bd. VI, H. 3.

Romanes[11] says, in revising the opinions of Weismann, "(1) Germ Plasm ceases to be continuous in the sense of having borne a perpetual record of congenital variations from the first origin of sexual propagation. (2) On the contrary, *as all such variations have been originated by the direct action of external conditions*" (italics mine) "the continuity of the germ plasm in this sense has been interrupted at the commencement of every inherited change during the phylogeny of all plants and animals, unicellular as well as multicellular. (3) But germ plasm remains continuous in the restricted though highly important sense of being the sole repository of hereditary characters of each successive generation, so that acquired characters can never have been transmitted to progeny, 'representatively,' even though they have frequently caused those 'specialized' changes in the structure of the germ plasm, which, as we have seen, must certainly have been of considerable importance in the history of organic evolution."

Here the inheritance of characters acquired by the soma is admitted, and the process is after the method of Diplogenesis. According to Romanes, Galton originally propounded this doctrine. Galton's language[12] is as follows:

"It is said that the structure of an animal changes when he is placed under changed conditions; that his offspring inherit some of his change, and that they vary still further on their own account, in the same direction, and so on through successive generations until a notable change in the congenital characteristics of the race has been effected. Hence, it is concluded that a change in the personal structure has reacted on the sexual elements. For my part, I object to so general a conclusion for the following reasons. It is universally admitted that the primary agents in the processes of growth, nutrition and reproduction, are the same, and that a true theory of heredity must so regard them. In other words, they are all due to the development of some germinal matter variously located. Consequently, when similar germinal matter is everywhere affected by the same conditions, we should expect that it would be everywhere affected in the same way. The particular kind of germ whence the hair sprang that was induced to throw out a new variety in the cells nearest the surface of the body under certain changed conditions of climate and food, might be expected to throw out a similar variety in the sexual elements at the same time. The changes in the germs would everywhere be collateral, although the moments when any of the changed germs happen to receive their development might be different." This is the first statement of the doctrine of Diplogenesis with which I have met and it appears to me to furnish the most rational basis for the investigation into the dynamics of the process.

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[11] An Examination of Weismannism, Chicago, 1892, p. 169.

[12] Contemporary Review, 1875, pp. 343–4; Proceeds. Royal Soc., 1872, no. 136.